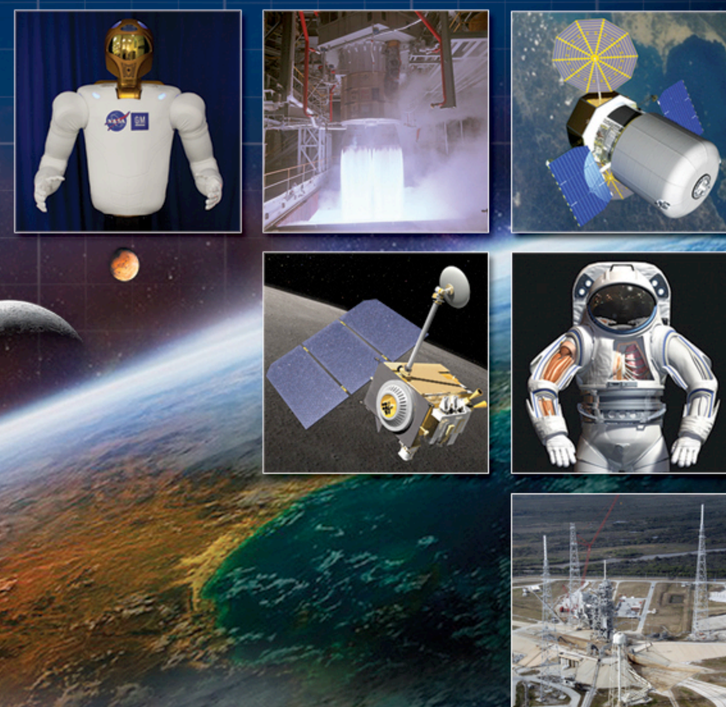
National Aeronautics and Space Administration

A New Space Enterprise of Exploration

Flagship Technology Demonstration-4

Aerocapture, Entry, Descent & Landing



Michelle Munk

26 May 2010

Disclaimer

- This chart set was presented on May 26, 2010 at the NASA Exploration Enterprise Workshop held in Galveston, TX. The purpose of this workshop was to present NASA's initial plans for the potential programs announced in the FY2011 Budget Request to industry, academia, and other NASA colleagues. Engaging outside organizations allows NASA to make informed decisions as program objectives and expectations are established.

- The following charts represent at "point of departure" which will continue to be refined throughout the summer and the coming years. They capture the results of planning activities as of the May 25, 2010 date, but are in no way meant to represent final plans. In fact, not all proposed missions and investments fit the in budget at this time. They provide a starting point for engagement with outside organizations (international, industry, academia, and other Government Agencies). Any specific launch dates and missions are likely to change to reflect the addition of Orion Emergency Rescue Vehicle, updated priorities, and new information from NASA's space partners.

The AEDL Problem

- AEDL system drives the mission architecture
  - Missions with Entry or re-entry
  - Orbit, site accessibility, location, elevation, landed mass, etc.
- 950 kg payload (MSL) is current upper limit for Mars surface missions
  - At the upper limit of today's technology (Viking-base)
  - Need new alternatives
- The Mars Problem
  - Too much atmosphere to land like we do on the Moon
    (Aeroheating, winds, density variations & fuel ruin it)
  - Too little atmosphere to land like we do at Earth
    (With 1% of Earth, imagine landing the Shuttle at 100,000 ft)
- Orbit Insertion Problem
  - Larger vehicles and/or high arrival speeds are limited by propellant mass
  - Aerocapture provides a lower mass alternative

Sustained and coordinated investments in new atmospheric flight system technologies enable larger surface payloads, larger orbital vehicles and higher arrival speeds

The Aerocapture Advantage

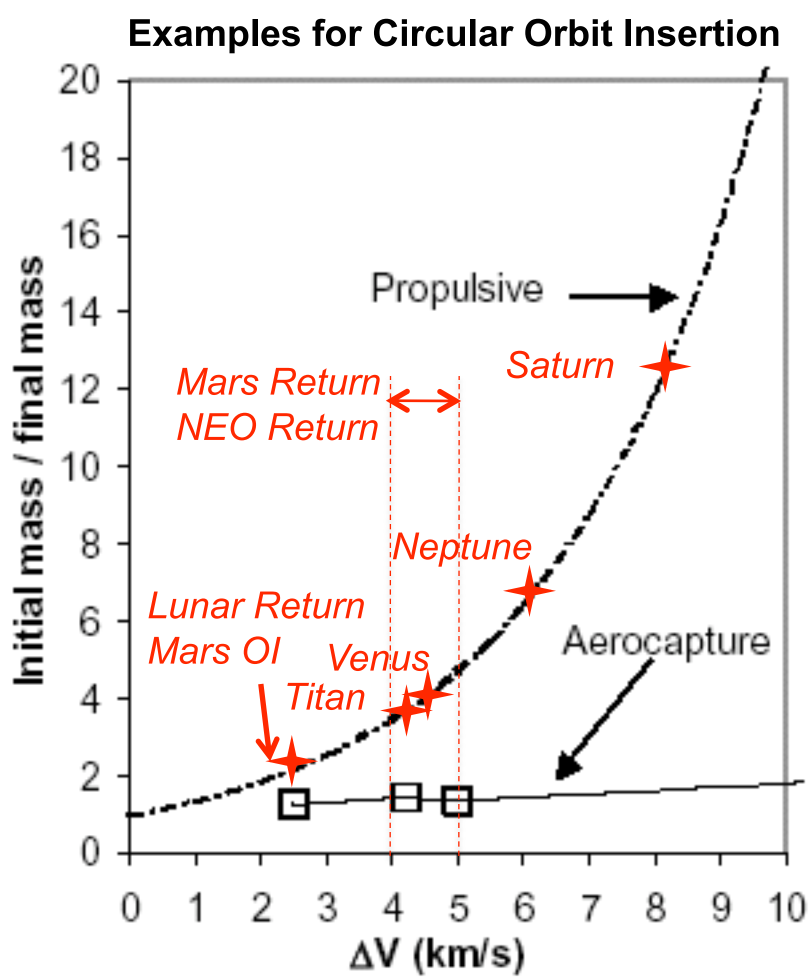
- The ΔV necessary to slow from a hyperbolic approach trajectory to a useful science orbit is

$$\Delta V = V_{phyp} - V_{circ}$$

- The rocket equation shows why aerocapture is so advantageous, masswise:

$$\frac{m_i}{m_f} = \exp\left(\frac{\Delta V}{I_{sp} g_0}\right)$$

- For a propulsive capture, the mass increases exponentially with the ΔV; for aerocapture, the mass of the aeroshell is linear with ΔV.



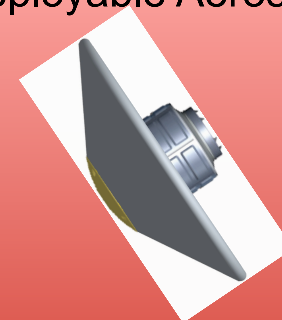
Aerocapture can provide a direct benefit of reduced launch mass or enable previously unattainable destinations

New (Potentially Mission Enabling) EDL Technologies

Hypersonic

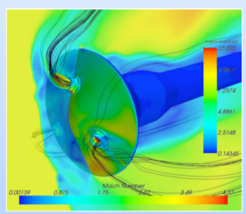
Rigid Mid L/D Aeroshells

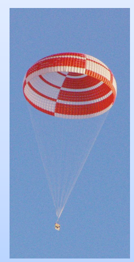
Inflatable/ Deployable Aeroshells



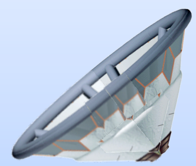
Supersonic

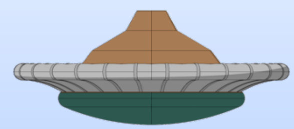
Supersonic Retro-propulsion

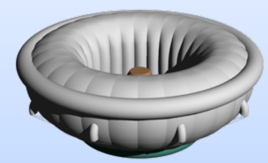




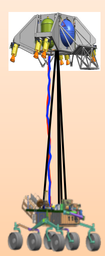
Inflatable/ Deployable Decelerators





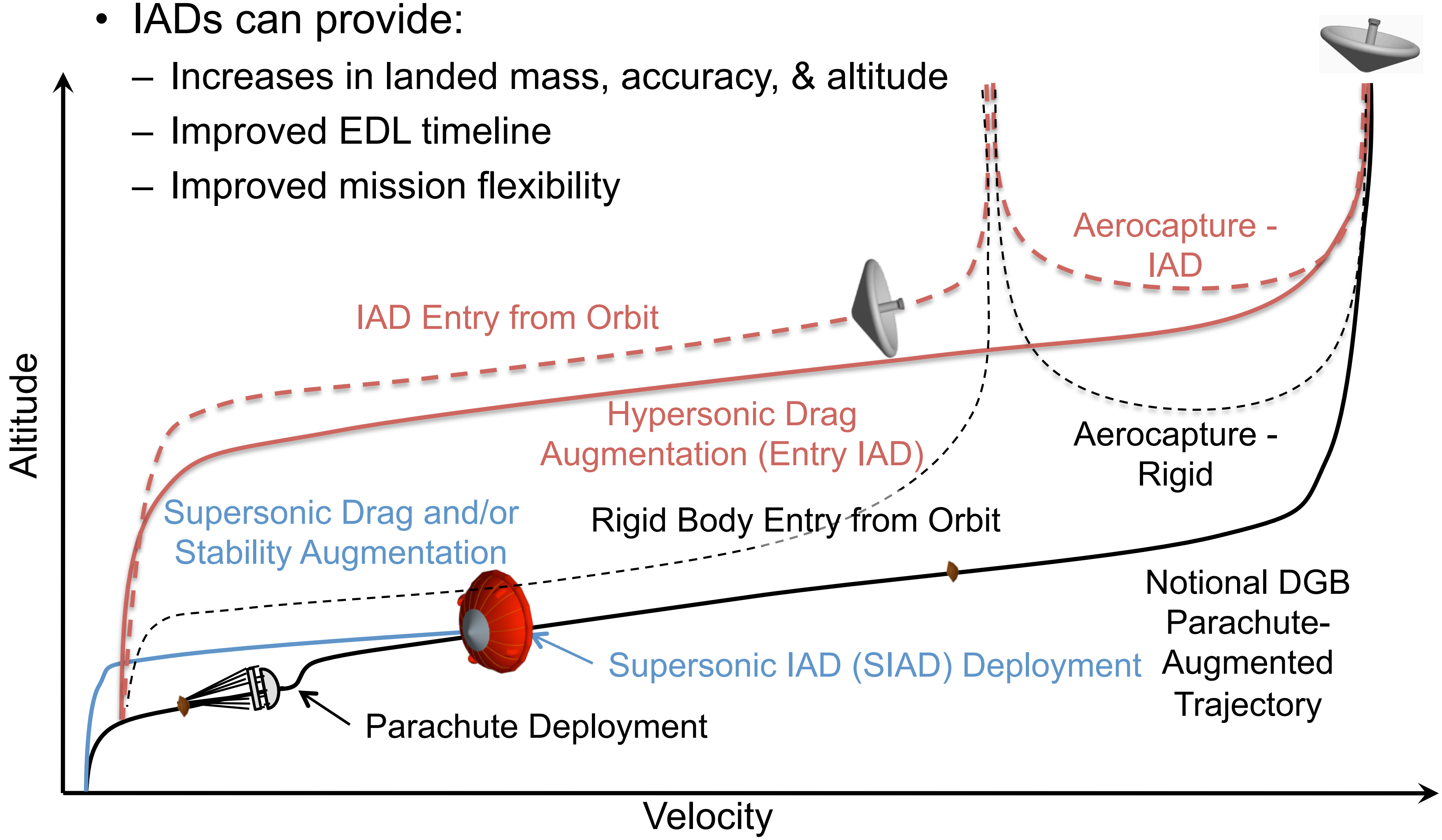


Subsonic / Terminal Descent



AEDL Application Space

- New Methods are needed to enable increased mass to Mars surface
- IADs can provide:
  - Increases in landed mass, accuracy, & altitude
  - Improved EDL timeline
  - Improved mission flexibility

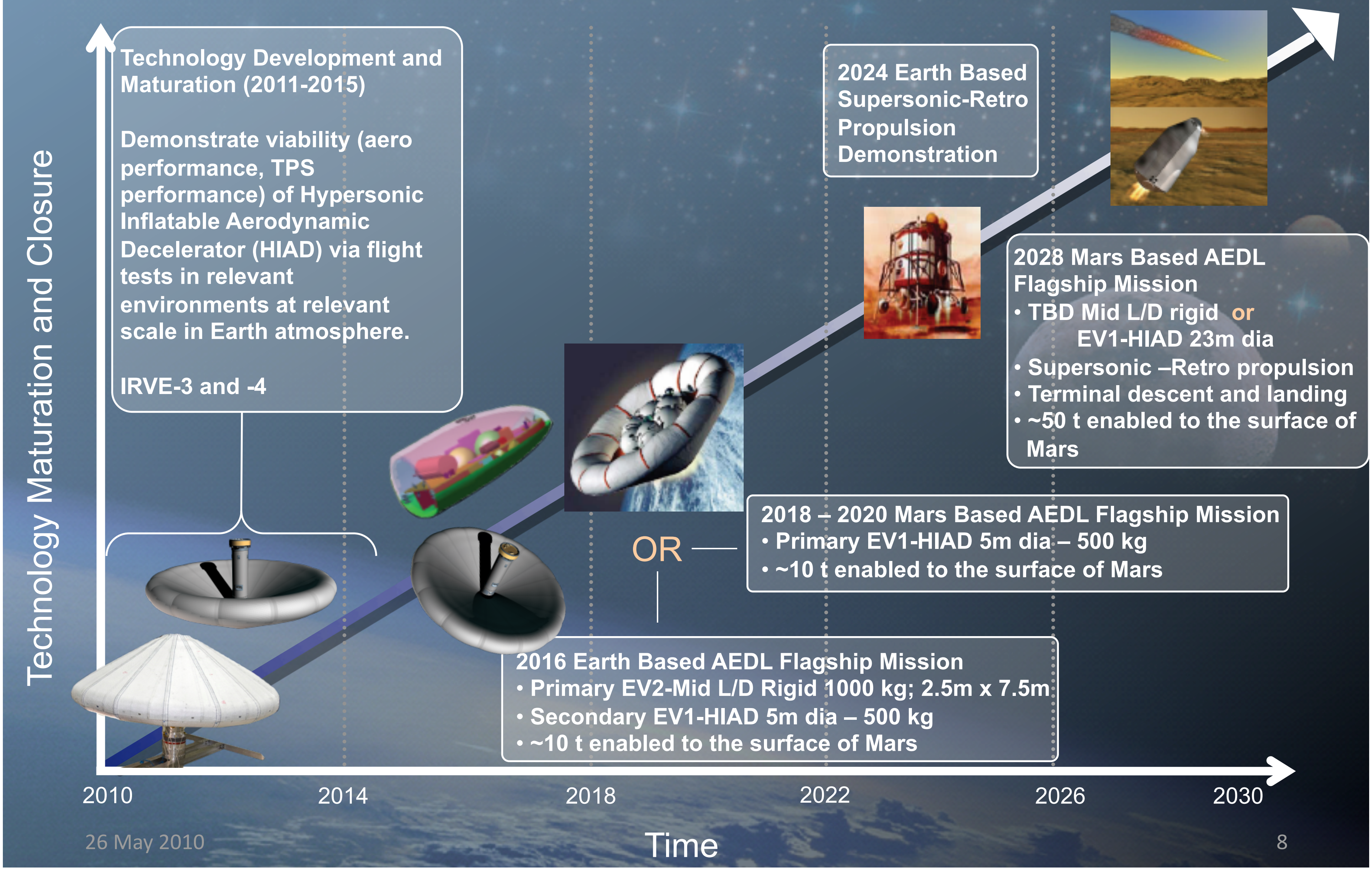


Needs, Goals, and Objectives *(From the RFI)*

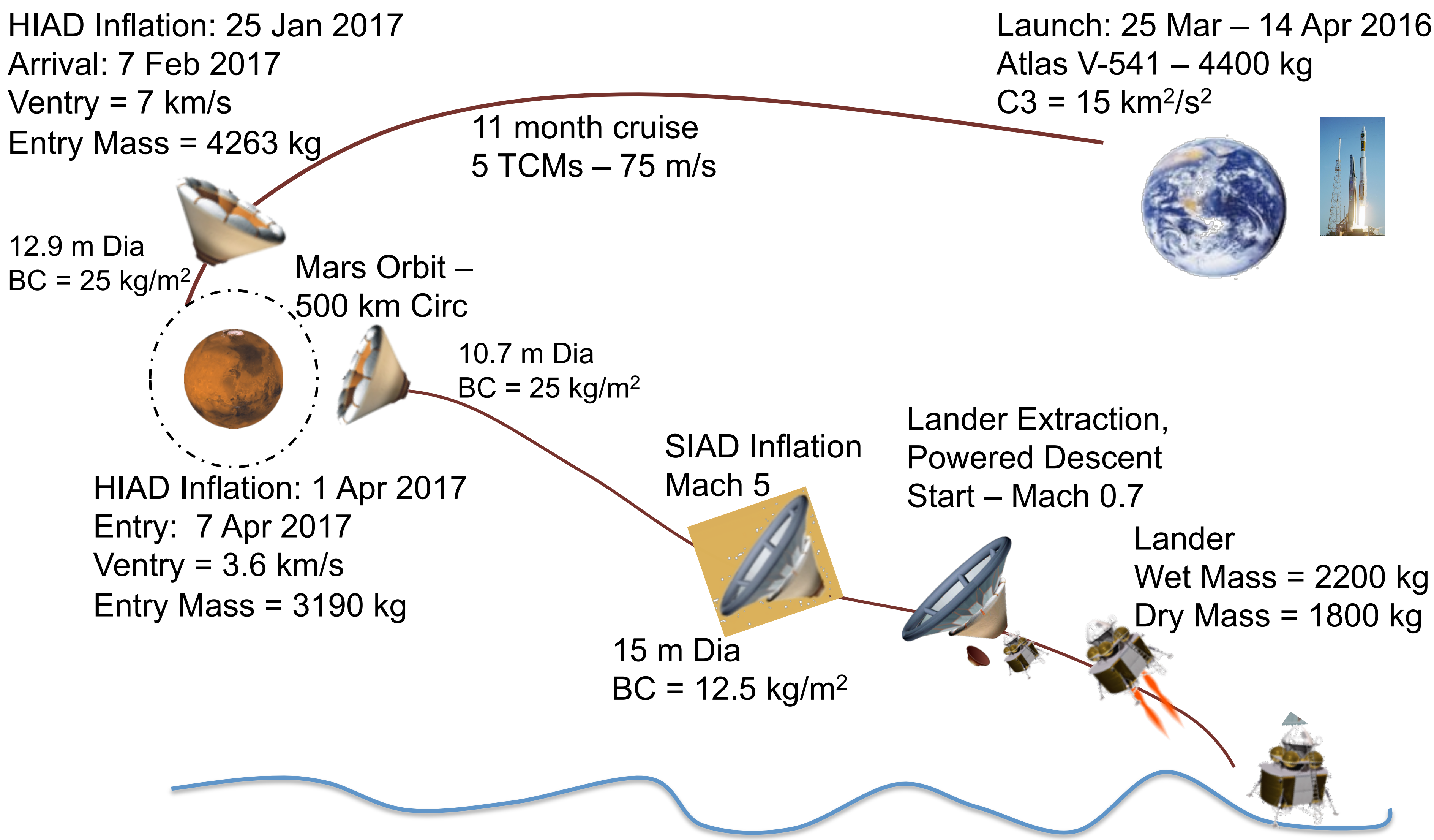
Technology Goals	Technology Objectives
Technology Goal 5: Advance, demonstrate and integrate technologies needed for Aerocapture and Entry, Descent and Landing of space vehicles for use at multiple destinations	**Objective 5-1:** Demonstrate ability to deploy, fly and control a large inflatable/deployable aeroshells in combination with flexible Thermal Protection systems (TPS)
	Objective 5-2: Demonstrate ability for high precision placement of payload on both low-G and high-G worlds
	Objective 5-3: Demonstrate improved ability for missions to use planetary atmospheres for orbit capture

Parameter	State-of-the-Art	Post-Flagship
Mars Surface Payload	1 mT	10 mT
Landing Accuracy	10 km	1 km
Landing Site Altitude	0 km	+1 km

Aero-EDL Capability Development in Support of Flagship Demonstrations



Mars-Based Aeroassist Demonstration Con-ops
Baseline Aerocapture & EDL Tech Demo-HIAD & SIAD

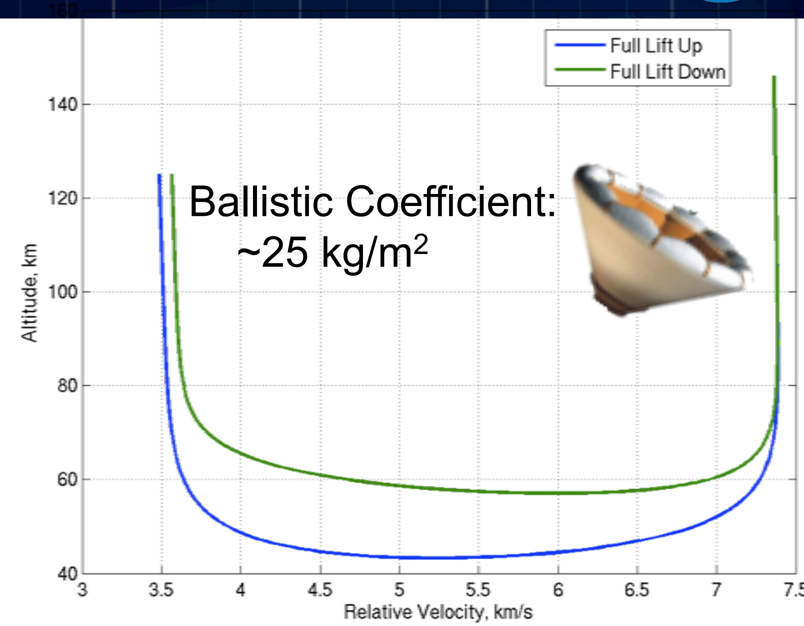


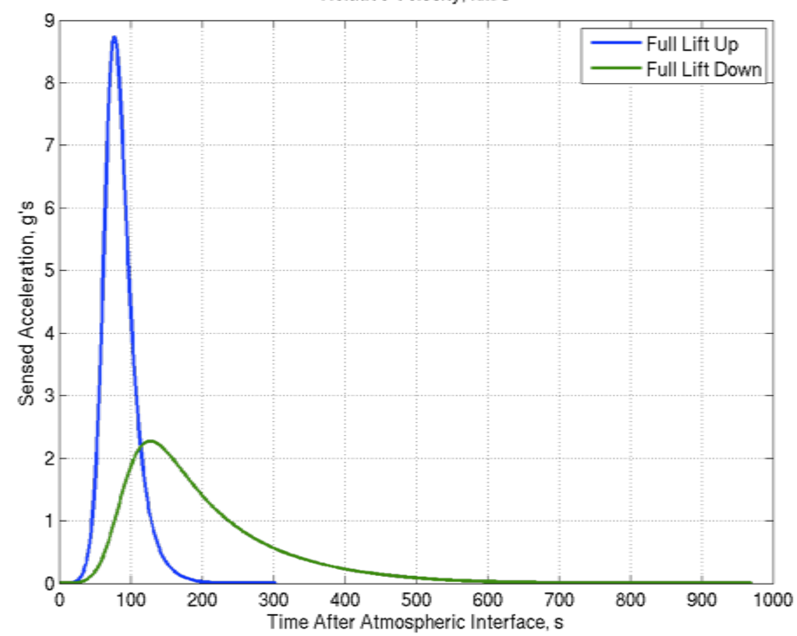
AEDL Environments - Mars Aerocapture

Maneuvers	Lift Up DV (m/s)	Lift Down DV (m/s)
Aeropass drag DV	3883	3803
Circ. + Raise	200	107

- Full Lift Up :
  - Angle of Attack = -17˚, Bank Angle = 0˚
  - Flight Path Angle= -12.3˚
  - Peak sensed acceleration: 8.7 g's
  - Minimum Altitude: 43 km
- Full Lift Down :
  - Angle of Attack = -17˚, Bank Angle = 180˚
  - Flight Path Angle= -9.5˚
  - Peak sensed acceleration: 2.3 g's
  - Minimum Altitude: 57 km

Flight path angle @ 125 km



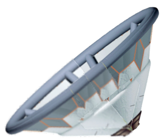


AEDL Mission Option Summary

Baseline: Mars

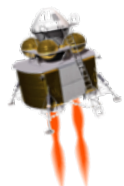
Aerocapture to 500 km Circ Orbit
13 m HIAD with Flex TPS and Control

Entry – 11 m HIAD with Flex TPS and Control



Supersonic Decel via 15 m SIAD

Alternative SIAD



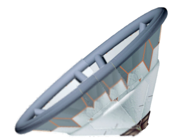
Subsonic Powered Descent

Option 1: Mars

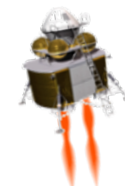
Aerocapture to 500 km Circ Orbit
2.25 m x 6.75 m Rigid Slender Mid L/D with Dual Heat-Pulse Capable TPS; Control via Body-Flap & RCS

Entry – second use of TPS; Control via Body-Flap & RCS

Lander Separation at Mach 4.5 via Solid Rocket Motors



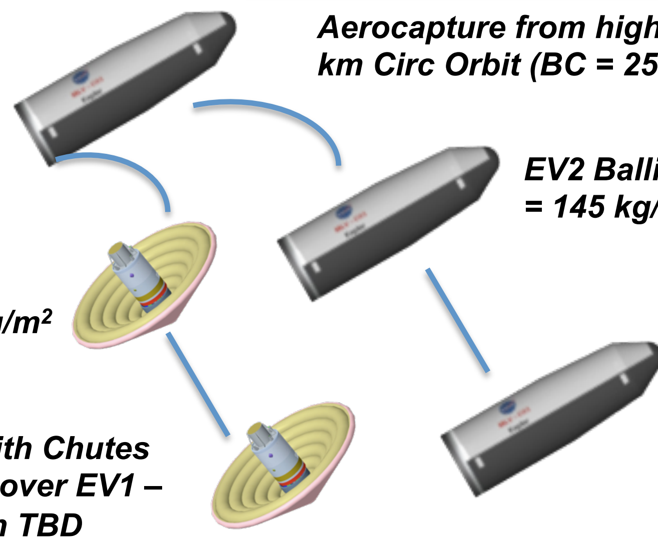
Supersonic Decel via 15 m SIAD



Subsonic Powered Descent

Options 2 and 3: Earth

OR



Aerocapture from high ellipse to 800 km Circ Orbit (BC = 250 kg/m²)

EV2 Ballistic Coeff = 145 kg/m²

EV1 Ballistic Coeff = 15 kg/m²

Decel with Chutes and Recover EV2 – Location TBD

Decel with Chutes and Recover EV1 – Location TBD

RFI Elements for AEDL Flagship

- Ensuring the key aspects and questions of Aerocapture and EDL are captured as part of the FTD mission
- Are the scaling issues and strategies reasonably well understood?
- Are the necessary fabrication and manufacturing facilities in existence and available?
- Are the necessary testing facilities in existence and available?
- How should the Point of Departure Missions be modified?

AEDL Flagship Summary

- Baseline mission has been defined – and concurred with by the AEDL community – with an optional configuration available
- Technology development and infusion strategy via OCT, ARMD, and ESMD has been defined - currently working development agreements with implementing organizations
- Basis of estimate developed to support FTD programmatic guidelines
- AEDL technologies can be ready for infusion by Mission level PDR
- ***Enabling increased mass to the surface of Mars (robotic – science or precursor; or human) requires development of new AEDL technologies which are demonstrated via the AEDL FTD***
- ***New AEDL technologies enable early use for Lunar and NEO returns***
- ***Mission Advocates/POCs:***
  - ***Henry.S.Wright@nasa.gov***
  - ***Michelle.M.Munk@nasa.gov***

Backup

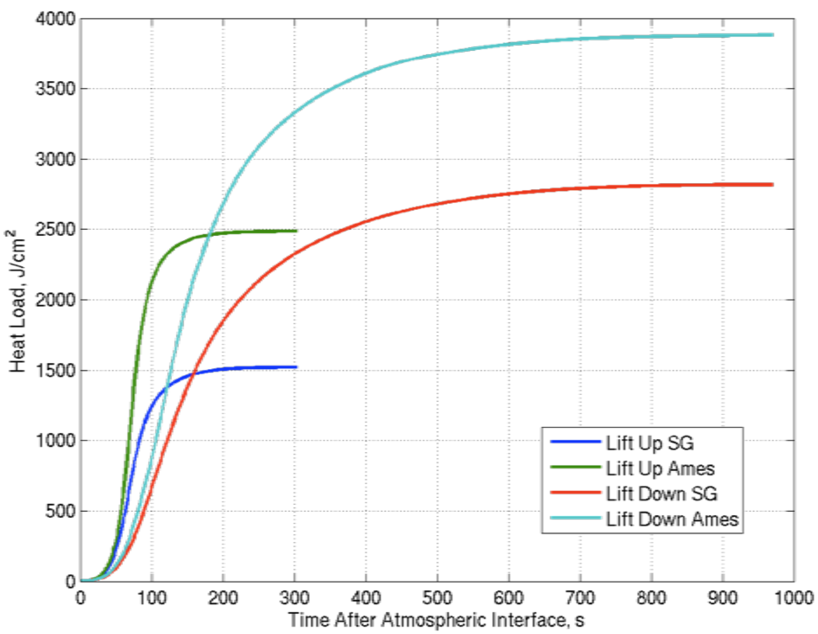
AEDL Environments – Mars Aerocapture & EDL

Element	Aerocapture	EDL
Entry Mass (kg)	4263	3190
Ballistic Coefficient (kg/m^2)	25 @ Mach 18	25 @ Mach 10
HIAD Diameter (m)	13	10.3
Peak Dynamic Pressure (Pa)	993	484
Peak Heat Rate (W/cm^2)	38	4
Total Heat Load (J/cm^2)	3300	533
SIAD Dynamic Pressure (Pa)		333
SIAD Deceleration (g's)		2.4
Powered Descent Thrust to Weight (Mars g's)		3.3
Powered Descent Initiation Altitude (km)		0.6
Powered Descent Propellant (kg)		250

Results of Mars Aerocapture and EDL environments/performance assessment are consistent with initial design study

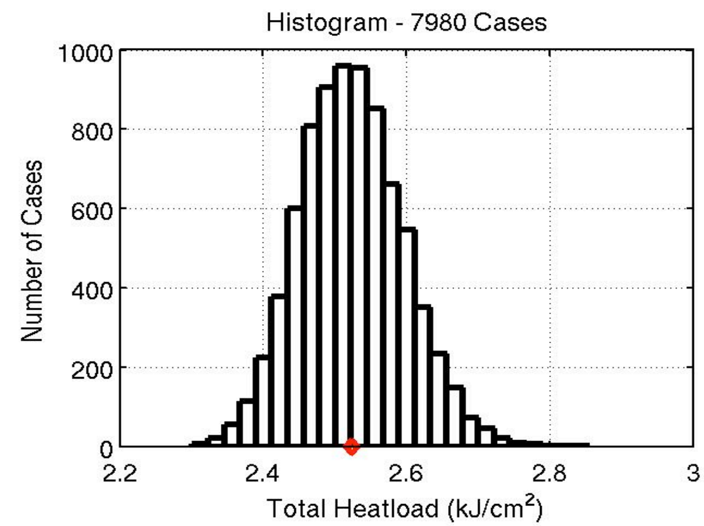
AEDL Environments - Mars Aerocapture

Full Lift Up/Down Bounding Method



- Total Heat Load (Sutton-Graves) – 2.8 kJ/cm^2
- Estimated Total Heat Load (Ames Indicator) – 3.3 kJ/cm^2
- Initial design Heat Load – 2.8 kJ/cm^2

Numerical Predictor-Corrector

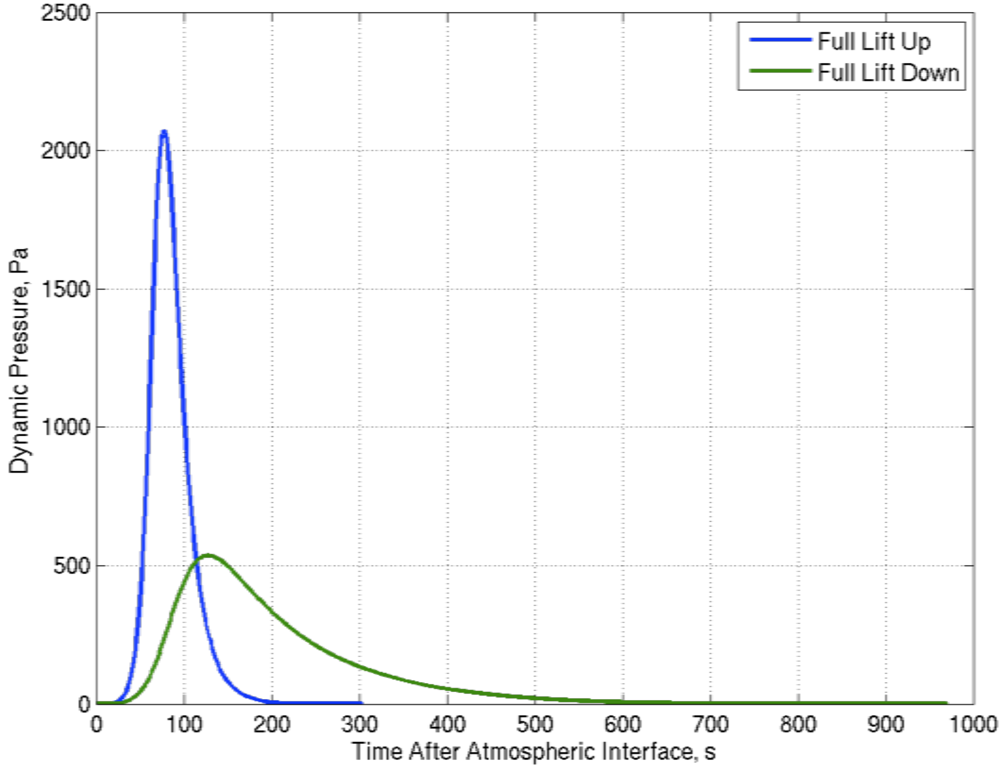


Statistics for
Total Heatload (kJ/cm^2):

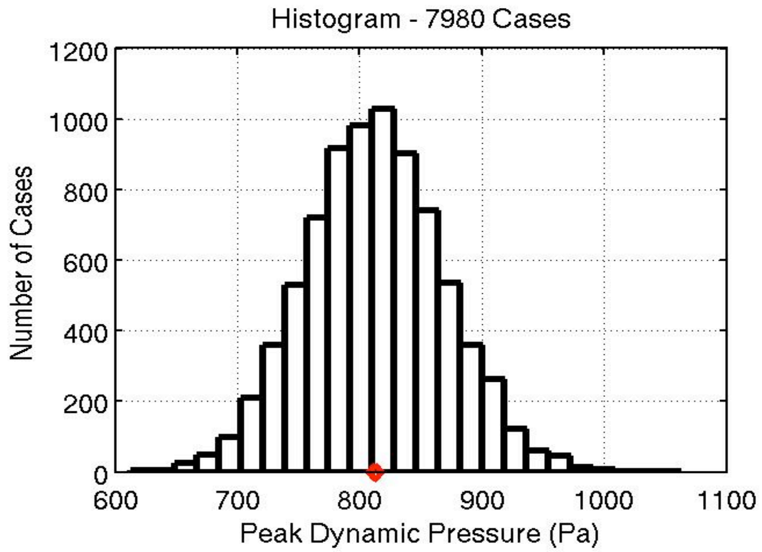
Mean = 2.5238
1-Sigma = 0.071813
3-Sigma = 0.21544
Minimum = 2.3014
00.13 %-tile = 2.3323
50.00 %-tile = 2.5214
99.87 %-tile = 2.7639
Maximum = 2.8556

AEDL Environments - Mars Aerocapture

Full Lift Up/Down Bounding Method



Numerical Predictor-Corrector

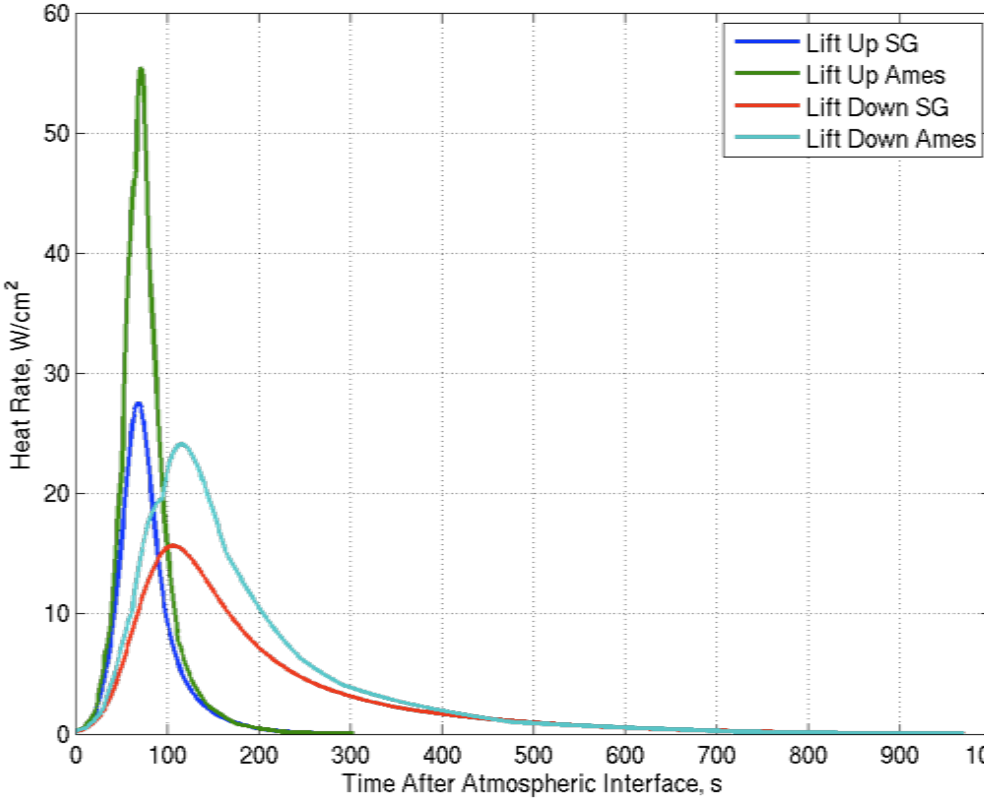


Statistics for
Peak Dynamic Pressure (Pa):

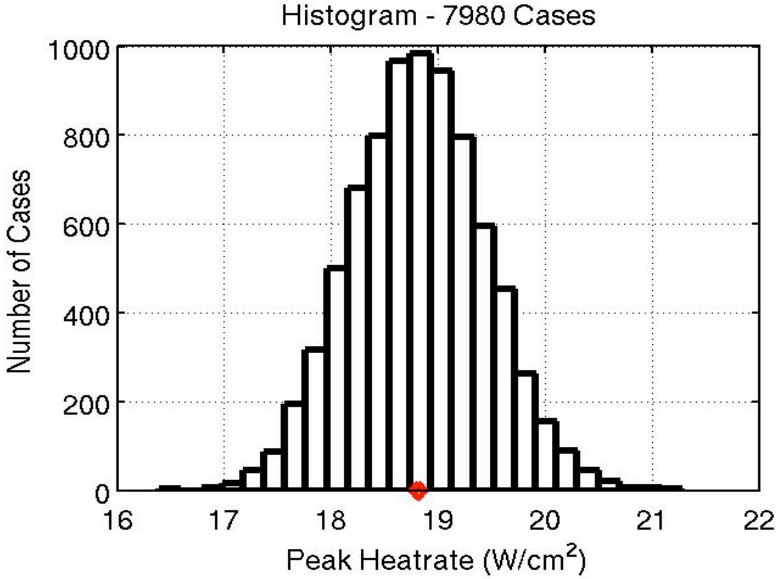
Mean = 812.7119
1-Sigma = 56.4987
3-Sigma = 169.4962
Minimum = 612.7617
00.13 %-tile = 654.0731
50.00 %-tile = 812.2296
99.87 %-tile = 993.0506
Maximum = 1062.1923

AEDL Environments - Mars Aerocapture

Full Lift Up/Down Bounding Method



Numerical Predictor-Corrector

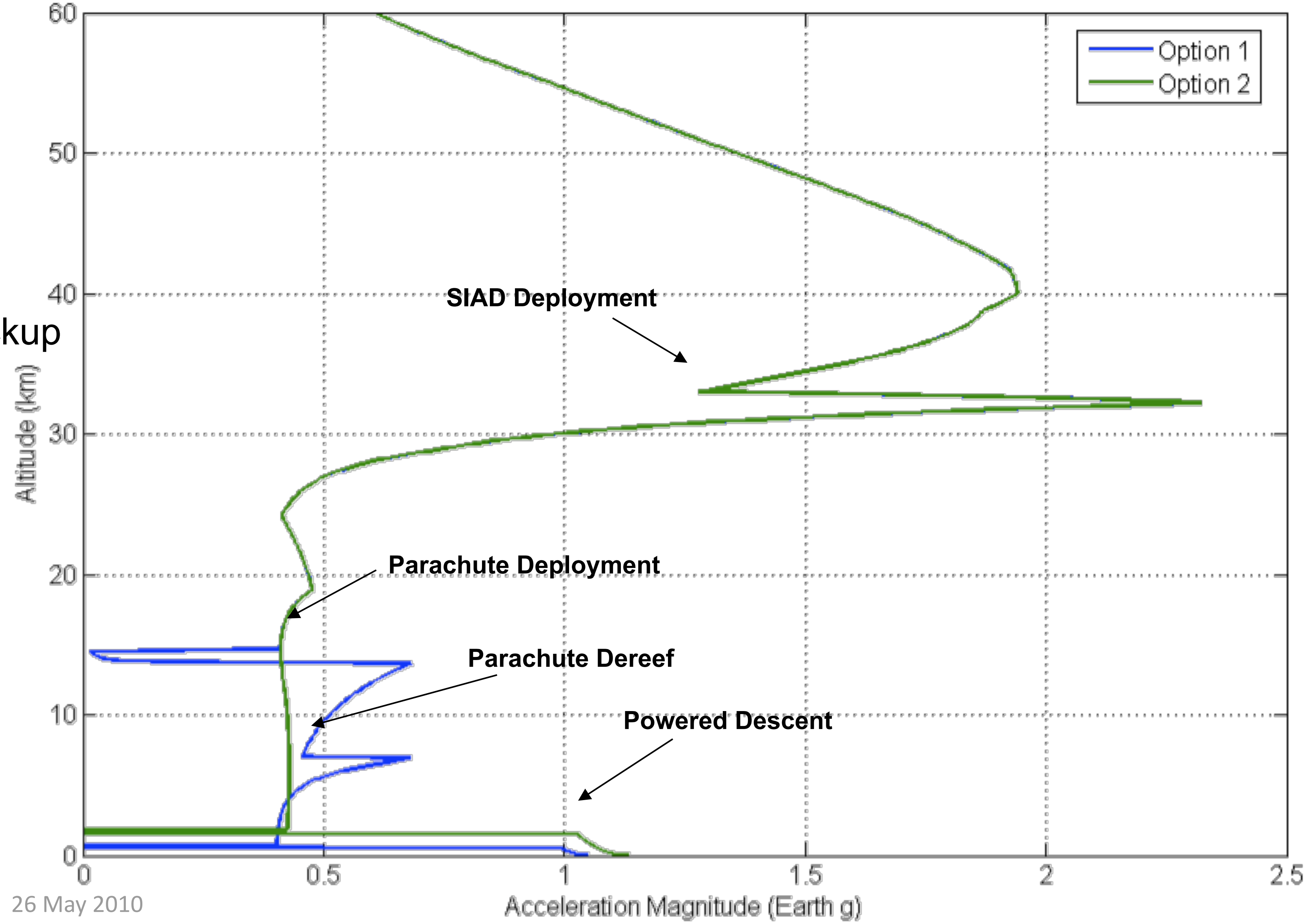


Statistics for
Peak Heatrate (W/cm^2):

Mean = 18.8186
1-Sigma = 0.62631
3-Sigma = 1.8789
Minimum = 16.3964
00.13 %-tile = 17.0578
50.00 %-tile = 18.8169
99.87 %-tile = 20.8813
Maximum = 21.279

AEDL Environments – Mars EDL Descent Acceleration Magnitude

Backup



Mass Table - Mars

Description	CBE (kg)	Growth Factor	Max Expected (kg)
ACS	67	10%	73
C&DH	22	10%	24
Harness	60	30%	78
Power	152	20%	182
Telecom	50	20%	60
Thermal	50	30%	65
Propulsion	251	25%	314
Structure	414	25%	517
Lander Sub-Total (Dry)	**1066**		**1313**
Payload	162	30%	211
Lander – Total	**1228**		**1524**
SIAD – Entry/Descent	155	30%	202
HIAD – Entry	237	30%	308
HIAD – Aerocapture	501	30%	651
Truss – Lander to Entry Rigid Nose + Guide Rails	82	25%	102
Truss – SC to PAF	61	25%	76
Spacecraft – Total – Dry	**2264**		**2863**
Spacecraft – Allocation – Dry (30% Margin)	**3235**		
Propellant – Allocation	**1165**		
Spacecraft – Total Allocation - Wet	**4400**		

C3 = 15 km^2/s^2: Atlas V-541 capability = 4460 kg

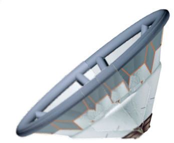
Mars-Based Aero-assist Demonstration
Aerocapture & EDL Tech Demo-HIAD & SIAD

Mission Description

- Advanced aero-capture and large mass delivery EDL technologies using instrumented in-situ Mars based flight technology demonstration system
- Can use either rigid or flexible vehicles
  - Hypersonic Inflatable Aero Decelerators (HIAD)
  - Supersonic Inflatable Aero Decelerators (SIAD)
  - GN&C – Ability to control “flexible structure”
  - TPS – flexible performance
  - Deployment after extended storage
  - Fluid-Structures Interactions
  - Terminal Descent and Landing ALHAT demo

Aerocapture to 500 km Circ Orbit
13 m HIAD with Flex TPS and Control

Entry – 11 m HIAD with Flex TPS and Control



Supersonic Decel via 15 m SIAD

Alternative SIAD

Subsonic Powered Descent

Goals and Objectives

Enable higher mass missions–and higher altitude landing sites–on Mars and other destinations with atmosphere and enhance the Earth-EDL stage of round-trip missions to the moon and elsewhere.

	SOA	Post-Flagship
Mars Surface Payload	1 mT	10 mT
Landing Accuracy	10 km	1 km
Mars Destination Altitude	0 km	+1 km

Partnerships: Technology experiments could be flown as payloads of opportunity. Potential partners would include ETDD, xPRP, OCT, ARMD, SMD, ESA, industry, and commercial launch providers

Notional Key Mission Milestones:
- Start-up 2011
- Mission launched in 2016/2018
- Mission Duration: 13 months

Secondary Payload Opportunities:
- Radiation, materials science, surface robot, ISRU, ALHAT, Lox/CH4 Descent

Option 1: Mars-Based Aeroassist Demonstration
Aerocapture & EDL Tech Demo-Rigid/Slender

Mission Description

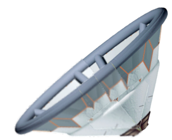
•Advanced aero-capture and large mass delivery EDL technologies using instrumented in-situ Mars based flight technology demonstration system

•Can use either rigid or flexible vehicles
- Rigid Slender Mid L/D Shape
- Control of slender structure via Body Flap & RCS
- TPS – Dual Heat-Pulse capable rigid
- Supersonic Inflatable Aero Decelerators (SIAD)
- SIAD Deployment after extended storage
- Fluid-Structures Interactions
- Terminal Descent and Landing ALHAT demo

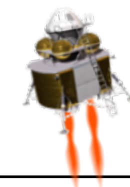
Aerocapture to 500 km Circ Orbit
2.25 m x 6.75 m Rigid Slender Mid L/D with Dual Heat-Pulse Capable TPS; Control via Body-Flap & RCS

Entry – second use of TPS; Control via Body-Flap & RCS

Lander Separation at Mach 4.5 via Solid Rocket Motors



Supersonic Decel via 15 m SIAD



Subsonic Powered Descent

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Partnerships: Technology experiments could be flown as payloads of opportunity. Potential partners would include ETDD, xPRP, OCT, ARMD, SMD, ESA, industry, and commercial launch providers

Notional Key Mission Milestones:

•Start-up 2011

•Mission launched in 2016/2018

•Mission Duration: 13 months

Secondary Payload Opportunities:

•Radiation, materials science, surface robot, ISRU, ALHAT, Lox/CH4 Descent